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2. Patent application number *(The Patent Office will fill this part in)* — 0326867.9 — 17 NOV 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

CHURCHILL DRILLING TOOLS LIMITED
33 ST SWITHINS STREET
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Patents ADP number *(if you know it)* — 8558934001

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention — IMPROVED BYPASS TOOL

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

CRUIKSHANK & FAIRWEATHER
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Patents ADP number *(if you know it)* — 547002

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Continuation sheets of this form	
Description	26
Claim(s)	
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Request for a substantive examination (Patents Form 10/77)	
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11. I/We request the grant of a patent on the basis of this application.

Signature(s) CRUIKSHANK & FAIRWEATHER Date 17.11.03

12. Name, daytime telephone number and e-mail address, if any, of person to contact in the United Kingdom ANDREW SHANKS 0141 221 5767

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IMPROVED BYPASS TOOL

FIELD OF THE INVENTION

The present invention relates to a bypass tool, and in particular to a fluid actuated downhole bypass tool.

BACKGROUND OF THE INVENTION

In the oil and gas industry, bores are drilled from surface to access subsurface hydrocarbon-bearing formations. In such a drilling operation, a drill bit is mounted on the end of a long "string" of pipe sections, and may be rotated from surface or by a motor located adjacent the drill bit. Drilling fluid or "mud" is pumped from surface down through the tubular string, to exit the drill bit via jetting nozzles. The drilling fluid then passes back to surface via the annulus between the drill pipe string and the bore wall. The drilling fluid serves a number of purposes, one being to carry drill cuttings away from the drill bit and then up through the annulus to surface. For a number of reasons, and particularly in highly deviated or extended reach wells, drill cuttings will sometimes gather in the annulus, restricting the flow of drilling fluid to surface and causing numerous other problems.

One method of clearing drill cuttings from the annulus is to provide one or more bypass tools in the drill string. These tools allow drilling fluid to flow directly into the annulus from an intermediate part of the drill pipe string, without having to pass through the drill bit and other tools normally located towards the end of a drill string, which tools collectively form a bottom hole assembly (BHA). As a result, the fluid entering the annulus via the bypass tool is at higher velocity and is more effective at carrying and clearing the drill cuttings from the annulus.

There have been many proposals to provide fluid actuated bypass tools, relying on a differential pressure force created by the flow of fluid through the tool to open the tool, usually by translating a sleeve to permit flow through a number of flow ports in the wall of the tool body. However, in some proposals the string bore may be completely blocked to actuate the tool, for example by dropping a ball from surface to land on a seat and create a piston which is pushed downwards by fluid pressure above the ball. The ball may subsequently be displaced, for example by squeezing the ball through the seat. However, many drilling engineers are reluctant to completely close the string in this way, and the loss of fluid circulation

below the tool may have an adverse effect on fluid operated tools and devices in the BHA.

The most effective flow actuated bypass tools tend to include nozzles or flow restrictions to create a fluid-flow related opening force; see, for example, applicant's WO 01/06086, the disclosure of which is incorporated herein by reference. However, particularly in circumstances where there is an elevated pressure differential between the tool interior and the annulus, such bypass tools often prove difficult to open. Furthermore, in circumstances where it is only possible to achieve a restricted fluid circulation flow rate, and thus a restricted fluid pressure force across the nozzle, it may be difficult to achieve the force necessary to open the bypass tool.

Even where a bypass tool is successfully opened in a high pressure differential situation, there is also often a problem relating to the initial flow of fluid through the tool flow ports: as the tool opens, the high differential pressure will induce a high velocity flow, which may result in erosion of areas of the tool, and the high velocity flow may also wash out the seals adjacent the flow ports, one of which must pass across the flow ports as the tool is opened. In particular, parts of the seals may be displaced and pushed or sucked through the

flow ports, such that when the tool subsequently closes the seals are guillotined, rendering the tool useless.

Thus, although flow-operated bypass tools are currently being successfully used by many operators, the wider use of such tools is restricted by a number of limiting operating parameters, primarily differential pressure and available flow rate, and operation beyond these boundaries tends to have a negative effect on tool reliability and dependability. Accordingly, it is among the objectives of embodiments of the present invention to provide bypass tools capable of operating reliably over a wide range of hydrostatic pressures, differential pressures and flow rates.

SUMMARY OF THE INVENTION

According to the present invention there is provided a fluid-actuated tool comprising:

a body comprising a valve arrangement including at least one flow port in a wall of the body and whereby the port may be selectively opened and closed; and

a flow restriction operatively associated with the valve arrangement and upstream of the at least one flow port whereby fluid flow through the restriction creates a port opening force and whereby the flow restriction has a variable, flow-related configuration.

In use, the provision of a flow restriction having a flow-related configuration offers many advantages. In particular, at lower flow rates it may be necessary or desirable to have a tight or narrow restriction, in order to achieve the differential pressure force across the restriction necessary to open the port. However, once the port is open it may then be possible to increase the flow rate. If the increase in flow rate is accompanied by an increase in the flow area of the restriction the port opening force may be maintained while the losses created by the restriction are minimised. In certain embodiments it may be possible to isolate the valve arrangement from the restriction, such that at higher flow rates the restriction may open up, without affecting the valve configuration. This is of particular advantage in downhole bypass tools, where difficulties in circulating drilling fluid may be the result, or cause, of low fluid circulating flow rates. However, if the bypass tool is provided with a particularly tight flow restriction this will only exacerbate the problem during normal operations when the bypass tool remains closed, due to the high level of losses induced by the restriction.

Preferably, the tool is a downhole tool, though embodiments of the invention may find application in surface or sub-sea applications.

Preferably, the tool is a bypass tool, though embodiments of the invention may find application in other tools, such as chemical injection tools.

Preferably, the valve arrangement may be selectively isolated from the flow restriction such that flow through the restriction does not impact on the valve configuration. This is useful in circumstances where it is not necessary or desirable to open or close the port, such that an operator may vary the flow rate through the restriction in the knowledge that such flow rate variations will not inadvertently open the port. Preferably, the means for selectively isolating the valve arrangement from the flow restriction is flow actuated. In a downhole application, this allows an operator to control the means from surface simply by varying the pump rate, for example by increasing or decreasing the pump flow rate, or simply by turning the pumps on and off. The means may take any appropriate form, at the simplest level providing means for releasably retaining the valve arrangement in an initial configuration, for example. Such means may include shear or sprung pins. In preferred arrangements however, means are provided for controlling the interaction between the restriction and the valve arrangement, for example by providing a cam arrangement or providing a J-slot arrangement such that the means may be

cycled between different configurations. In a preferred arrangement, the means is arranged such that it may be continuously cycled, for example by providing a 360-degree or otherwise continuous slot and follower pin.

The flow restriction may take any appropriate form, and is preferably in the form of a nozzle or choke. Preferably, the configuration of the restriction is variable by changing the flow area defined by the restriction in response to flow-related forces experienced by the restriction. Preferably, the restriction normally defines a smaller flow area, which may be zero; in this case there is normally no flow through the restriction. The restriction may be spring biased towards this smaller flow area configuration; a given flow rate will create a greater differential pressure force across the restriction in this configuration. On experiencing a pressure differential force above a predetermined level the restriction may be reconfigured to define a larger flow area, and thus present less of an impediment to flow. This may be achieved by mounting part of the restriction on a spring, such that the part moves when the differential pressure force acting on the part overcomes the spring force. Movement of the part may be damped, for example by locating the spring in a chamber which changes

volume as the part moves, and controlling the rate of flow of fluid from or into the chamber.

Preferably, the flow restriction comprises at least two relatively movable parts, the parts being movable to vary the degree of restriction. In one embodiment, the restriction comprises an orifice and a spear, the orifice being axially movable relative to the spear to vary the area of the annulus between the spear and the orifice.

The flow restriction may be integral with the tool body. Alternatively, the flow restriction may be provided as a separate unit and may be located in the tool body as and when required, for example in a somewhat similar manner to the sleeve as described in applicant's WO 01/06086. Thus, the tool body may be provided in, for example, a drill string and remain dormant, presenting little or no restriction to fluid flow, until required. The restriction, which may take the form of a sleeve incorporating a variable orifice, may then be pumped from surface through the string to land on and engage with the body. If desired, the restriction may also be retrievable.

Preferably, the valve arrangement comprises a sleeve, which is one or both of axially and rotatably movable relative to a body wall portion. One or both of the sleeve or body wall may define the one or more flow ports.

The sleeve may be biased towards a position to close the ports. Preferably, the sleeve is mounted internally of the body. Seals may be provided between the sleeve and the body, to limit or prevent flow of fluid through the ports when the sleeve is positioned to close the ports. The seals may take a conventional form, for example seal members in the form of elastomeric O-rings or chevron seals. In one embodiment of the invention, at least on one side of the one or more flow ports, there are no seal members provided. Rather, the cooperating sleeve and body surfaces are very close fitting. Typically this is achieved by forming the surfaces of a relatively hard material, such as tungsten carbide or a ceramic, and then grinding the surface down to a high tolerance. As a result, the clearance between the annular surfaces may be the order of a few thousandths of an inch. Under pressure, fluid will flow through this "micro" annulus. However, because of the limited dimensions of the annulus the fluid velocity will be low, typically in the order of 1 inch/second, such that the energy and the volume of the leakage will be low. The low flow velocity and the hard surfaces will limit or prevent wear of the surfaces.

According to another aspect of the present invention there is provided a downhole differential pressure seal arrangement between relatively movable surfaces, the seal

arrangement comprising cooperating relatively movable surfaces defining a clearance therebetween, the clearance being selected to permit a low velocity and low energy flow of liquid therebetween.

The seal arrangement may be provided in a bypass tool or the like. In a bypass tool, the seal arrangement may be provided in a valve arrangement including at least one flow port in a wall of the body and whereby the port may be selectively opened and closed. The seal arrangement is preferably provided on the side of the flow port which is initially opened, that is at least one of the surfaces will be in the initial flow path through the port. With conventional seal members, particularly elastomeric O-ring seals, there is a risk that the initial high velocity flow through the opening port will wash part of the seal member into the port, such that the seal member is guillotined when the port is subsequently closed. However, with this aspect of the invention there is no separate seal member, such that there is no risk of this form of failure.

Furthermore, although not wishing to be bound by theory, the applicant believes that replacing one or more conventional seals in a downhole differential pressure seal arrangement will significantly decrease the level of force necessary to move the adjacent sealed parts, as described below. In a conventional downhole tool, such as

a flow actuated bypass tool, a sleeve is mounted within the tool body and is axially movable relative to the body to open or close flow ports; typically, both the sleeve and the body define flow ports which may be aligned to provide a flow path between the tool bore and the surrounding annulus. The sleeve will typically be spring-biased towards the closed position. The sleeve may be coupled to a nozzle or choke such that flow through the choke creates a differential pressure across the orifice, tending to move the sleeve to open the flow ports. Conventionally, calculations relating to the flow rate necessary to move the sleeve to the open position are made with reference to the return spring force. However, the applicant has identified that there are other significant forces which must be considered, in particular the frictional forces created by the seals between the sleeve and the body, and which forces act to resist movement of the sleeve relative to the body. Conventional seals are energised by pressure, and in a downhole bypass tool the pressure acting on the seals has two main elements, hydrostatic pressure and differential pressure, that is the pressure created by the head of fluid in the bore above the tool, and the differential pressure between the interior of the tool and the exterior of the tool, which will vary depending upon a number of conditions, including

the sum of pressure drops below the tool and drilling fluid flow rate. The hydrostatic pressure acts on both sides of the seals and creates a level of friction that varies with mud weight and vertical depth and that must be overcome to move the sleeve relative to the tool body, both when opening and closing the tool. At low differential pressures, seal friction caused by the differential pressure is relatively low and easily predicted. However, as differential pressure increases, the seal friction increases exponentially.

While a degree of seal friction is useful, as it tends to damp movement of the sleeve, once the combined frictional effects induced by elevated hydrostatic and differential pressures are taken into account it becomes apparent why existing bypass tools become unpredictable and unreliable at higher hydrostatic and differential pressures.

This aspect of the invention obviates the pressure-related friction associated with conventional seals, thus facilitating operation of such downhole tools. In particular, the seal arrangement of the present invention reduces the forces required to open such tools, particularly at higher differential pressures, and renders the tool operating force substantially independent of pressure. It is thus possible to provide the necessary

tool opening force, at a particular flow rate, and independent of hole depth, mud weight and pressure drops below the tool, using a larger choke, for example a 1 inch diameter choke may suffice whereas a 7/8 inch choke, or smaller choke, would be required if conventional seals were being used. Of course this offers the advantage that the pressure losses induced by the choke are also reduced. In other cases, the invention may make it possible to open a choke-actuated bypass tool at differential pressures which previously made operation of such a tool impractical or impossible.

In certain embodiments, it may be useful to combine a seal arrangement in accordance with this aspect of the invention with a conventional seal. As noted above, within certain parameters conventional seals may provide a useful damping effect. In other embodiments, the damping effect normally supplied by a conventional seal may be provided by other means, for example a snap ring.

Although reference is made herein primarily to bypass tools and the like it will be apparent to those of skill in the art that the various aspects of the invention have application in other tools and devices. In particular, in a further aspect of the invention there is provided a tool comprising a body including a fluid actuated device including a flow restriction whereby fluid flow through

the restriction creates an actuating force and whereby the flow restriction has a variable, flow-related configuration.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figures 1 - 3 are graphs illustrating opening forces produced by chokes of different sizes in conventional bypass tools;

Figure 4a is a sectional view of a bypass tool in accordance with an embodiment of the present invention, shown in an initial closed configuration;

Figures 4b is a development of a cam arrangement for controlling the interaction between a flow restriction and a valve arrangement of the bypass tool of Figure 4a;

Figure 4c is an enlarged sectional view of the flow restriction of Figure 4a;

Figure 5a is a sectional view of the bypass tool of Figure 4a, showing the bypass tool open;

Figures 5b is a development of the cam arrangement of the bypass tool of Figure 5a;

Figure 6a is a sectional view of the bypass tool of Figure 4a, showing the bypass tool in a second open configuration;

Figures 6b is a development of the cam arrangement of the bypass tool of Figure 6a;

Figure 7a is a sectional view of the bypass tool of Figure 4a, showing the bypass tool in a second closed configuration;

Figures 7b is a development of the cam arrangement of the bypass tool of Figure 7a;

Figure 8 is a sectional view of a bypass tool in accordance with a further embodiment of the present invention, showing the tool in an initial closed configuration; and

Figures 9 and 10 are sectional views of alternative flow restrictions in accordance with further embodiments of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

Reference is first made to Figure 1 of the drawings, which is a graph showing the conventional understanding of opening forces in a downhole bypass tool. In particular, the tool features a sleeve provided in combination with a choke, this sleeve being normally spring biased to close flow ports in the tool body wall. By increasing the flow

rate through the choke, the differential pressure force developed across the choke may be increased, and when this force is higher than the spring force provided by the return spring the sleeve will move and open the flow ports.

Conventionally, a tool designer will simply choose the largest choke or nozzle which will open the tool at the desired flow rate, based on the information as portrayed in Figure 1. However, the present applicant has identified that this is a gross oversimplification of bypass tool operation.

Seals are provided between the sleeve and tool body, and these seals are energised by pressure; the higher the pressure the harder the seals will grip the mating surfaces, thus preventing leakage. However, the harder the seals grip, the more friction increases to prevent relative movement.

Seals in downhole tools experience both hydrostatic and differential pressure. As may be seen from the graph of Figure 2, the hydrostatic friction, resulting from the seals being subjected to pressure from the head of fluid standing in the well bore; is constant at a certain depth and mud weight. However, the seal friction due to differential pressure varies exponentially with flow rate. Thus, as may be seen from Figure 2, at a high differential

pressure (4000psi at 125 gpm) a $^{7}/_{8}$ inch choke will never produce sufficient force to open the tool ports.

Accordingly, in order to open the tool ports in a high differential pressure environment, a very tight choke or nozzle is required. This is however self-defeating as at high flow rates a very tight choke results in significant pressure losses; the reason for providing a bypass is to relieve pressure.

Another issue which must be considered when determining the operating parameters of a flow activated bypass tool is that one of the seals will have a port travel across the seal as the port is opened and closed. As conventional seal members are elastomeric and energised to the point of opening there is a tendency for the seal members to get sucked into the port and sealing function is subsequently lost. Better bypass tools are designed with this in mind, however even the best tools tend to have an upper differential pressure limit of around 2000 psi. As is apparent from the graphs shown in Figure 3, there remains the possibility of seal failure by this mechanism in certain circumstances.

From the above it is apparent that high differential pressures create a number of technical difficulties for the successful and reliable operation of a flow activated bypass tool.

As noted above, one of the main reasons for using a bypass tool is to relieve pressure, in particular to avoid the pressure losses incurred in pumping the drilling fluid through the BHA, in order to increase the flow rate in the upper annulus, which is often of a larger cross sectional area. In circumstances where there is a large differential pressure prior to opening the bypass tool, the available flow rate is usually low, thus the available opening force is correspondingly low.

Thus, the greater the need for the bypass tool to open, the less force available to open the tool and the greater the frictional resistance to opening. Various aspects of the present invention are intended to address these difficulties, as described below.

Reference is now made to Figure 4a of the drawings, which is a sectional view of a bypass tool in accordance with a preferred embodiment of the present invention. The tool 10 comprises a generally cylindrical body 12 defining an axial through bore 14. The body 12 is adapted to form part of an otherwise conventional drill string and thus features pin and box ends 16, 17 to allow coupling to adjacent pipe sections. Provided within the body 12 is a valve arrangement 18 including a valve sleeve 20. As will be described, flow ports 22 in the sleeve 20 may be aligned with flow ports 24 in the body 12 to allow

drilling fluid to flow directly from the tool bore 14 into the annulus 26 which, in use, will be defined between the exterior of the tool 10 and the surrounding bore wall. The tool is flow activated by means of a flow restriction 30. The tool body 12 may initially be provided in a drill pipe string without the flow restriction 30, such that there is no impediment to flow of drilling fluid through tool 10. However, when bypass is required, the flow restriction 30 may be pumped down to the tool 10 from surface, and Figure 4a shows the flow restriction 30 just before it engages with the tool body 12.

The valve sleeve 20 is normally biased to an upper position, as illustrated in Figure 4a, by a compression spring 32. In this position, the wall of the sleeve 20 bridges the flow ports 24. A conventional O-ring seal 34 is provided on the exterior of the sleeve 20 for location below the flow ports 24. However, the seal 36 above the flow ports 24 is of a different configuration. In particular, the seal 36 is provided by two co-operating surfaces 38, 39 of a harder material, in this example tungsten carbide, which have been ground to a high tolerance such that the annular gap between the surfaces 38, 39 is of the order of a few thousandths of an inch. In use, with the differential pressure acting across the seal 36, drilling fluid will flow through this micro-annulus 40

however, because of the minimal clearance, the fluid velocity will be low, in the order of 1 inch per second. Accordingly, the volume and kinetic energy of the leaking fluid will be correspondingly low. Furthermore, because the surfaces 38, 39 are very hard, there will be little if any damage to these surfaces. Thus, equilibrium will be maintained across the seal 36 and under normal drilling conditions the leakage of this through the seal 36 will not create any problems and will effectively remain unnoticed.

The upper end of the sleeve 20 co-operates with a restriction landing sleeve 40 having a profile 42 adapted to engage with a corresponding profile 44 provided on the upper end of the flow restriction 30. The landing sleeve 40 is biased towards an upper position relative to the body 12 by a further compression spring 46. The two sleeves 20, 40 interact via a track and pin arrangement, a development of which is illustrated in Figure 4b of the drawings. In particular, the upper end of the sleeve 20 features a number of radial inwardly directed pins 48 which engage with a continuous cam track 50 formed on an outer surface of the landing sleeve 40.

Reference is now also made to Figure 4c of the drawings, which illustrates the flow restriction 30 in greater detail. The flow restriction 30 comprises a

cylindrical collar 52 that provides mounting for a central spear 54 via an apertured plate 53. Mounted coaxially within the collar 52 is a sleeve 56, the upper end of which defines an orifice 58. A compression spring 60 acts between the sleeve 56 and the collar 52, to bias the sleeve 56 upwardly such that the orifice 58 is positioned around the spear 54. Thus, the flow restriction 30 normally defines a relatively tight choke, the area of the choke being the annulus defined between the orifice 58 and the spear 54.

The spring 60 is located within an annular spring cavity 61. To permit movement of the sleeve 56 relative to the collar 52 it is of course necessary for fluid to be able to pass from and into the cavity 61, as the volume of the cavity 61 changes. However, by providing a relatively small orifice through which fluid must flow from the cavity 61, it is possible to damp the movement of the sleeve 56.

As noted above, the tool body 12 will normally be incorporated in a drill string and the flow restriction 30 only pumped into the string when bypass is required. Reference is now made to Figure 5a of the drawings, which shows the flow restriction 30 engaged with the tool body 12. Furthermore, the flow of fluid through the tool bore 14 has created a differential pressure force across the

restriction 30. Initial downward movement of the flow restriction 30 induced by this differential pressure force compresses the spring 46 and moves the pins 48 from the initial dormant position 48a in the cam track 50 (Figure 4a) to a second position 48b where further axial movement of the restriction 30 and landing sleeve 40 produces corresponding movement of the valve sleeve 20, resulting in compression of both springs 32 and 46, and alignment of the flow ports 22, 24. Clearly, such movement of the valve sleeve 20 will only occur when the spring force provided by both springs 32, 46 has been overcome, in addition to the frictional resistance to movement provided by the O-ring seal 34. The other seal 36 will provide little or no resistance to movement.

If the operator continues to increase the flow rate through the string, the differential pressure force across the restriction 30 will continue to increase. Due to the sleeve 40 landing out on a shoulder 62 of a sleeve 64 fixed to the tool body 12, further axial movement of the sleeves 20, 40 is not possible. However, once the differential pressure force exceeds the orifice closing force provided by the spring 60, the sleeve 56 will be moved downwards to the position illustrated in Figures 6a of the drawings; the spring 60 is selected such that the tool is open before the there is any movement of the

sleeve 56. It will be noted that the sleeve 56 has been pushed downwardly beyond the end of the spear 54, such that the restriction to flow provided by the flow restriction 30 has now been considerably reduced. Thus, the pressure losses across the flow restriction 30 will be considerably less than they would have been had the restriction 30 been fixed in the configuration as illustrated in Figures 4 and 5.

If it is desired to close the flow ports 24 all that is required is for the operator to reduce the drilling fluid flow rate through the string and the tool 10 to the level where the differential pressure force across the flow restriction 30 is less than the return forces provided by the various springs 60, 46 and 32; in practice, this will tend to be achieved by simply turning off the pumps. The sleeves 20, 40 will return to their original positions as illustrated in Figures 4a, however, the follower pins 48 will now be in the position illustrated by numeral 48c in the cam track 50, as illustrated in Figure 6b.

If the operator then turns up the drilling fluid pumps once more, the flow restriction 30 together with the landing sleeve 40 will once again be pushed downwardly relative to the tool body 12. However, due to the location of the pins 48 in the cam track 50, the landing sleeve 40

may move downwardly, while the pin 48 moves towards position 48d (Figure 7b), without inducing corresponding movement of the valve sleeve 20, until the landing sleeve 40 itself lands out on the shoulder 62. Further increases in drilling fluid flow rate will result in the restriction sleeve 56 being moved downwards relative to the restriction collar 52, as is illustrated in Figure 7a of the drawings. Accordingly, in this configuration the pressure losses induced by the flow restriction 30 will be substantially less than would have been the case if the flow restriction was fixed in the configuration as illustrated in, for example, Figure 5a.

Reference is now made to Figure 8 of the drawings, which illustrates a tool 110 in accordance with an alternative embodiment of the present invention. The tool 110 shares many features with the tool 10 described above. However, it will be apparent that in place of the conventional o-ring seal 34 of the tool 10, the tool 110 features a seal 134 below the body flow ports 124 of similar form to the seal 36 above the flow ports 24 of the first embodiment. As noted above, this minimises seal friction that would otherwise resist movement of the valve sleeve 120 relative to the tool body 112.

As the movement of the sleeve 120 is resisted by little or no seal friction, such that the tool operating

forces are independent of depth and mud weight, the same nozzle or orifice may be used irrespective of the depth at which the tool is intended to operate, mud weight, and pressure losses below the tool. Also, a relatively light return spring may be used as there will be relatively little friction to overcome to return the sleeve 120 to the closed position. It will also be noted that this permits this particular tool 110 to be used with a flow restriction 130 having a relatively large fixed diameter choke 158.

However, in recognition that a conventional o-ring seal, such as the seal 34, provides a useful damping effect, a snap ring 137 is provided between the sleeve 120 and the body 112, to provide an initial resistance to movement of the sleeve 120, in addition to the force provided by the spring 132.

Reference is now made to Figures 9 and 10 of the drawings, which illustrate alternative flow restriction forms. In Figure 9, the flow restriction 230 is configured such that there is normally no flow permitted through the flow restriction, the orifice 258 defined by the upper end of the sleeve 256 being only very slightly larger than the outer diameter of the spear 254. Thus, the flow restriction 230 will initially act as a piston, until the pressure differential across the restriction 230 is

sufficient to compress the spring 260 and move the orifice 258 downwards and clear of the spear 254.

In the flow restriction 330 illustrated in Figure 10, it will be noted that the lower end of the spear 354 is tapered, such that there will be a gradual increase in the choke area as the sleeve 356 is pushed downwards relative to the collar 352.

Those of skill in the art will recognise that the above described embodiments of the present invention overcome many of the significant problems faced by conventional bypass tools, and it is anticipated that bypass tools made in accordance with embodiments of the present invention may be capable of operating under hydrostatic pressures in the range of 0 to 15000 psi and differential pressures between 0 and 4000 psi.

Those of skill in the art will also recognise that the above described embodiments are merely exemplary of the present invention, and that various modifications and improvements may be made thereto without departing from the scope of the present invention.

IBT Opening Forces

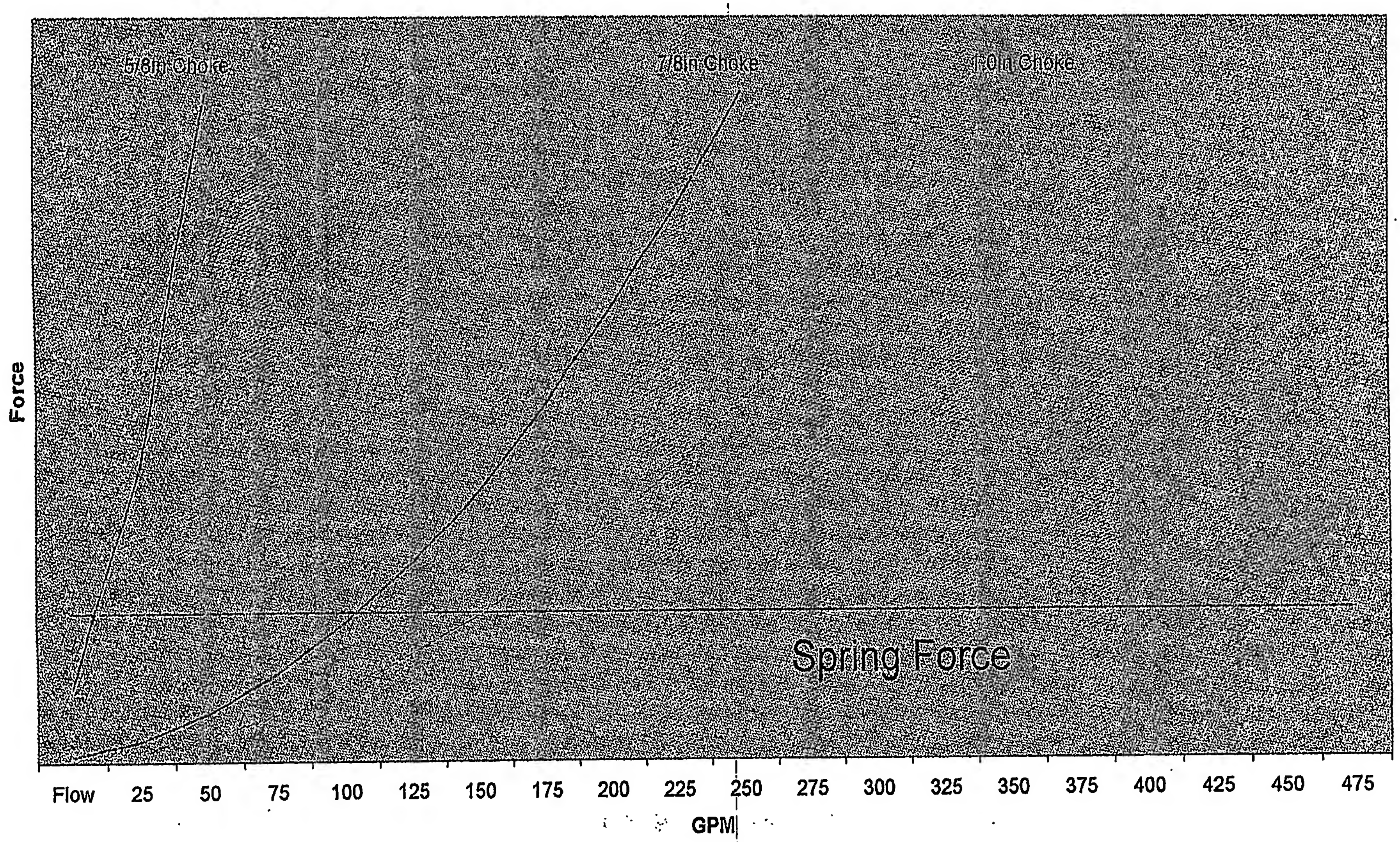


Figure 1

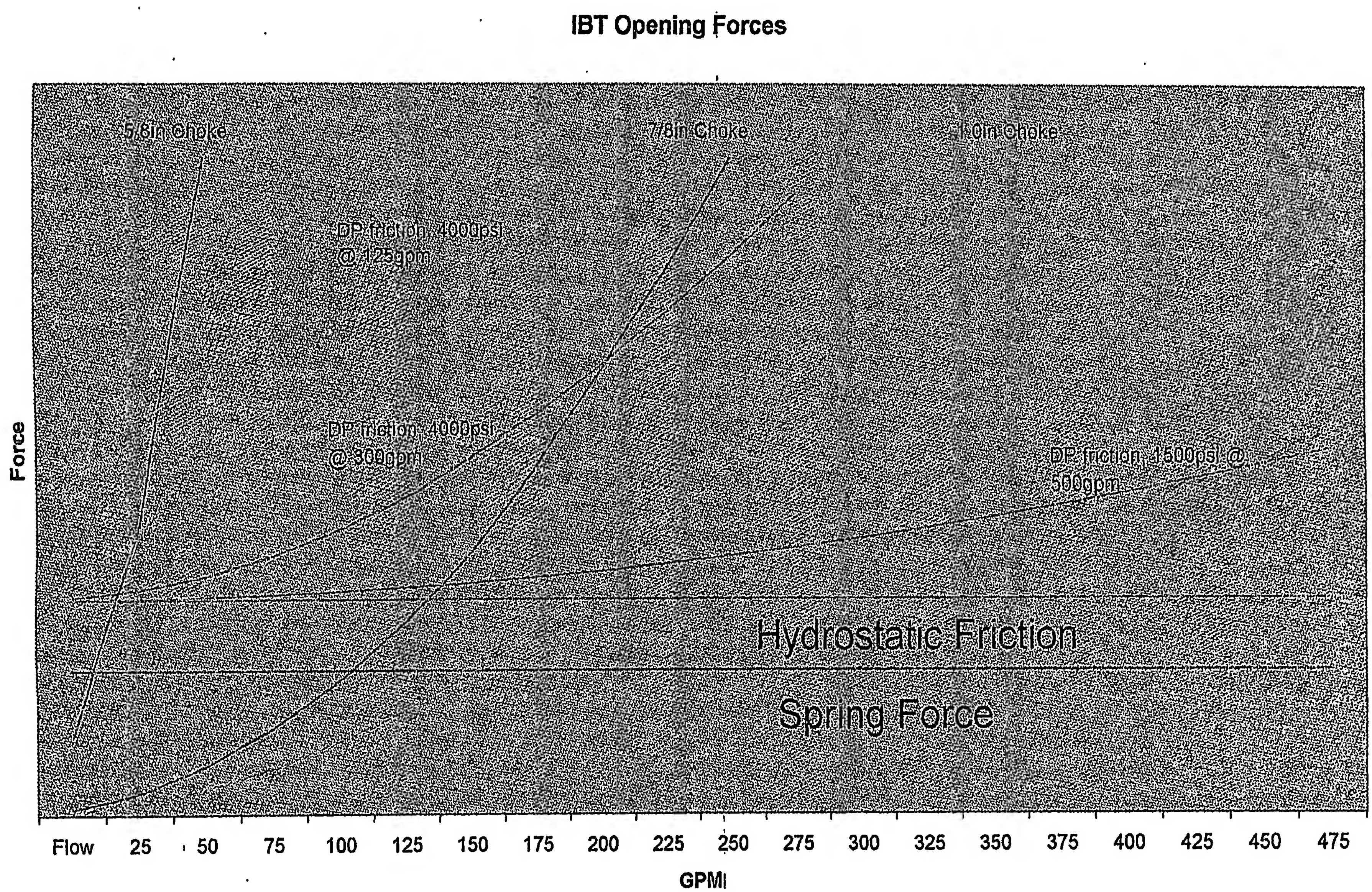

IBT Opening Forces
5/8in Choke
7/8in Choke
1.0in Choke
DP friction, 4000psi @ 125gpm
DP friction, 4000psi @ 300gpm
DP friction, 1500psi @ 500gpm
Hydrostatic Friction
Spring Force
Force
Flow
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
GPMI

Figure 2

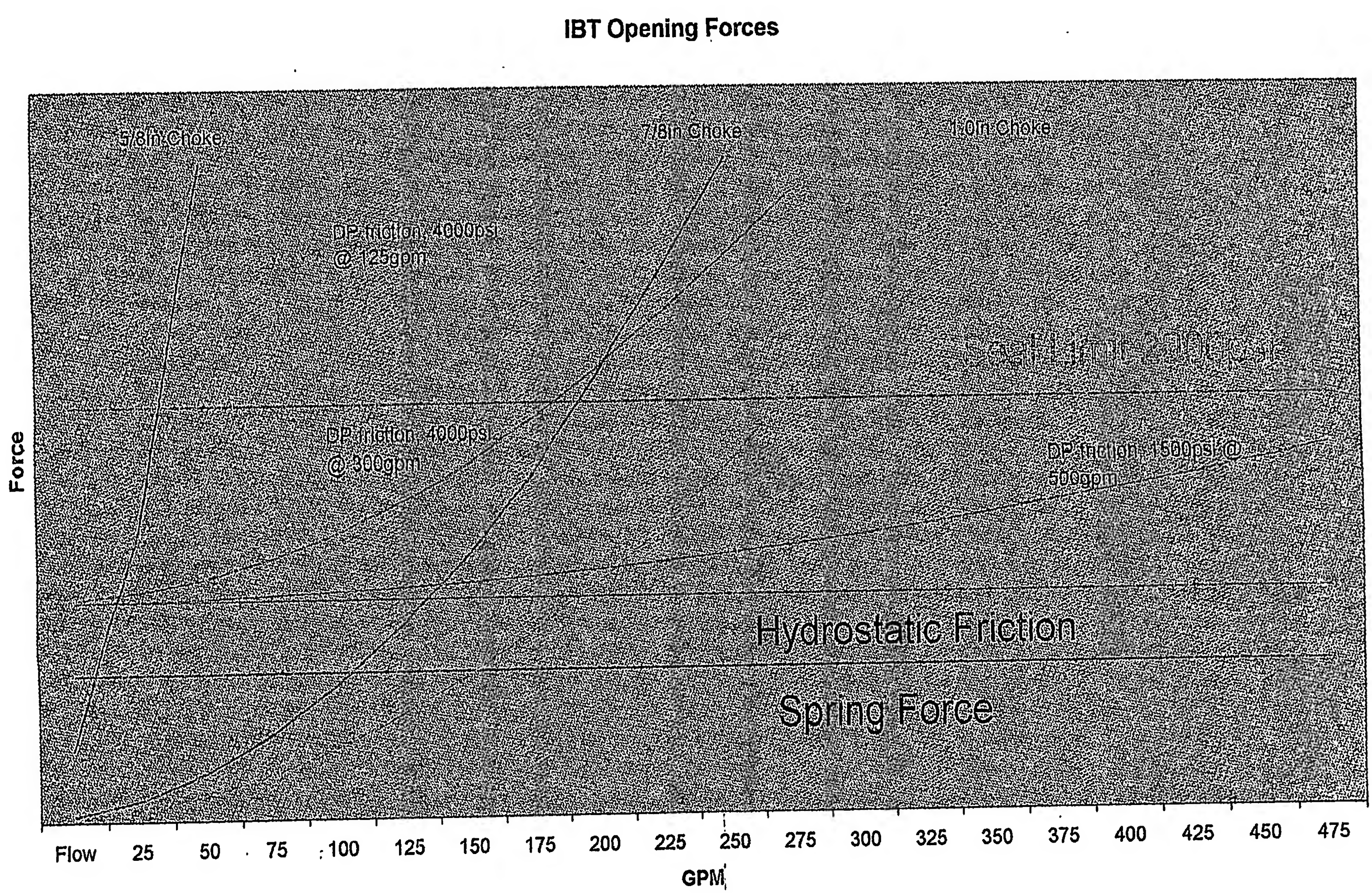

IBT Opening Forces
5/8in Choke
7/8in Choke
1.0in Choke
DP friction: 4000psi
@ 125gpm
DP friction: 4000psi
@ 300gpm
DP friction: 1500psi @
500gpm
Hydrostatic Friction
Spring Force
Force
Flow
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
GPM

Figure 3

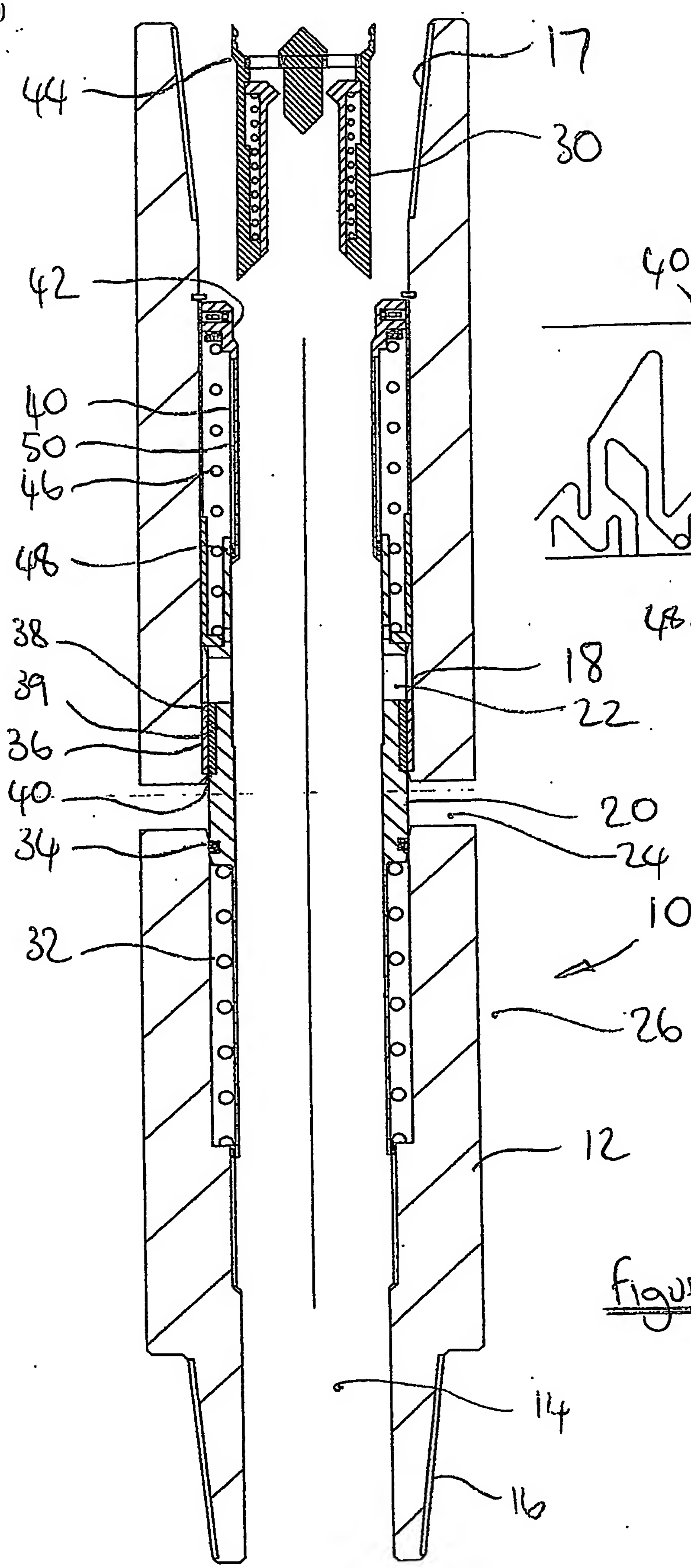


figure 4a

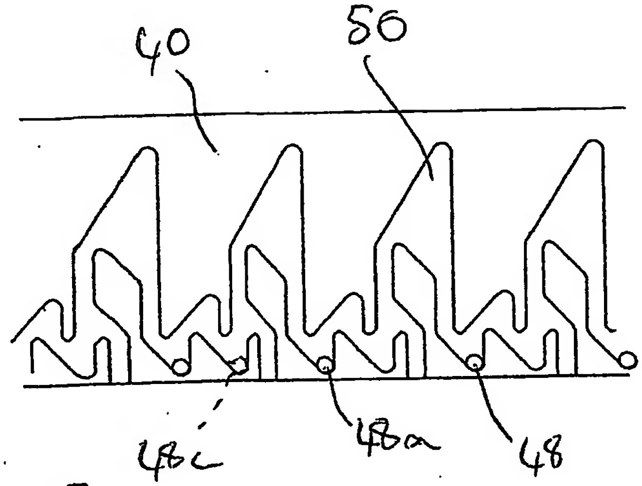


figure 4b

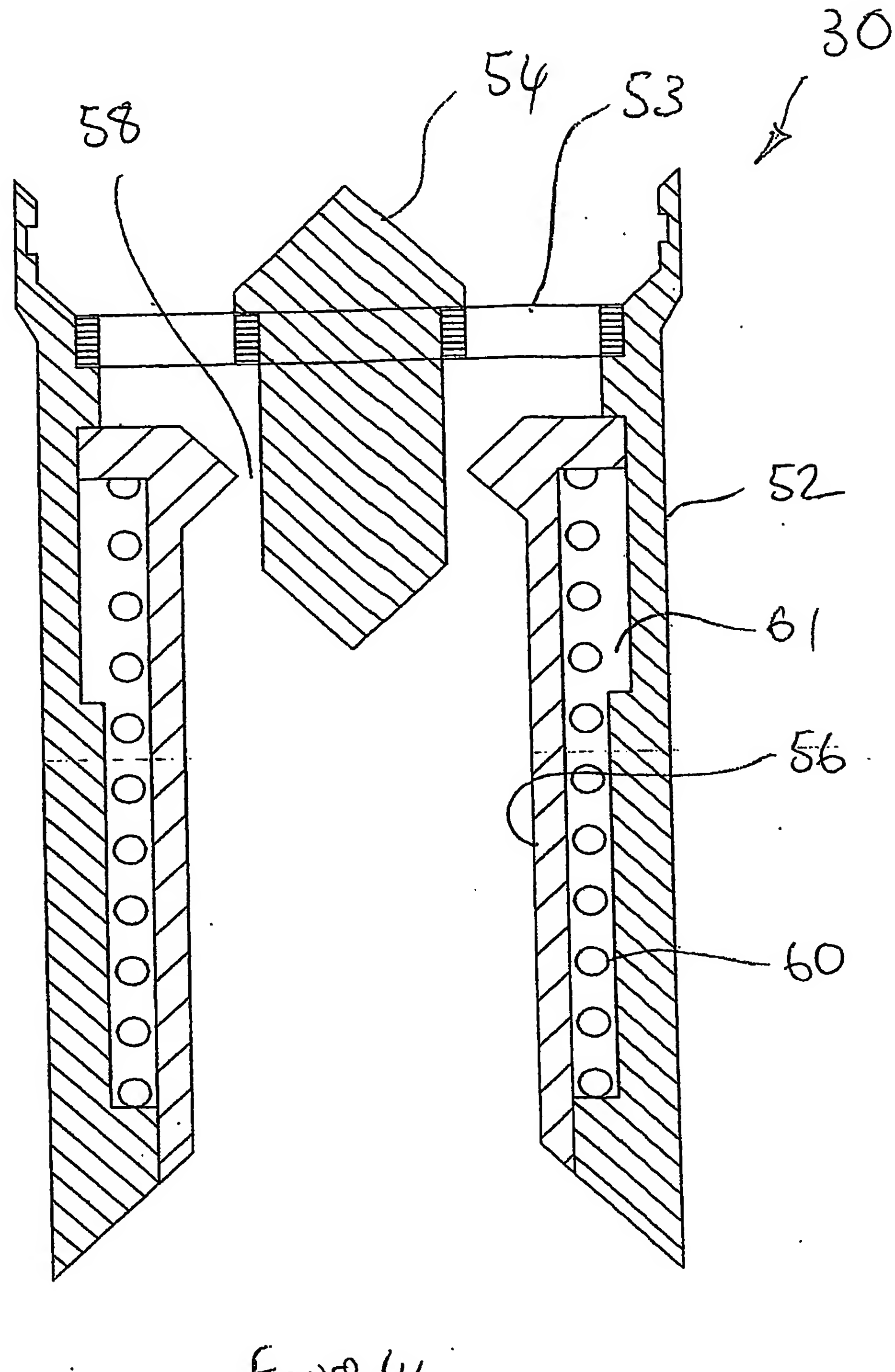
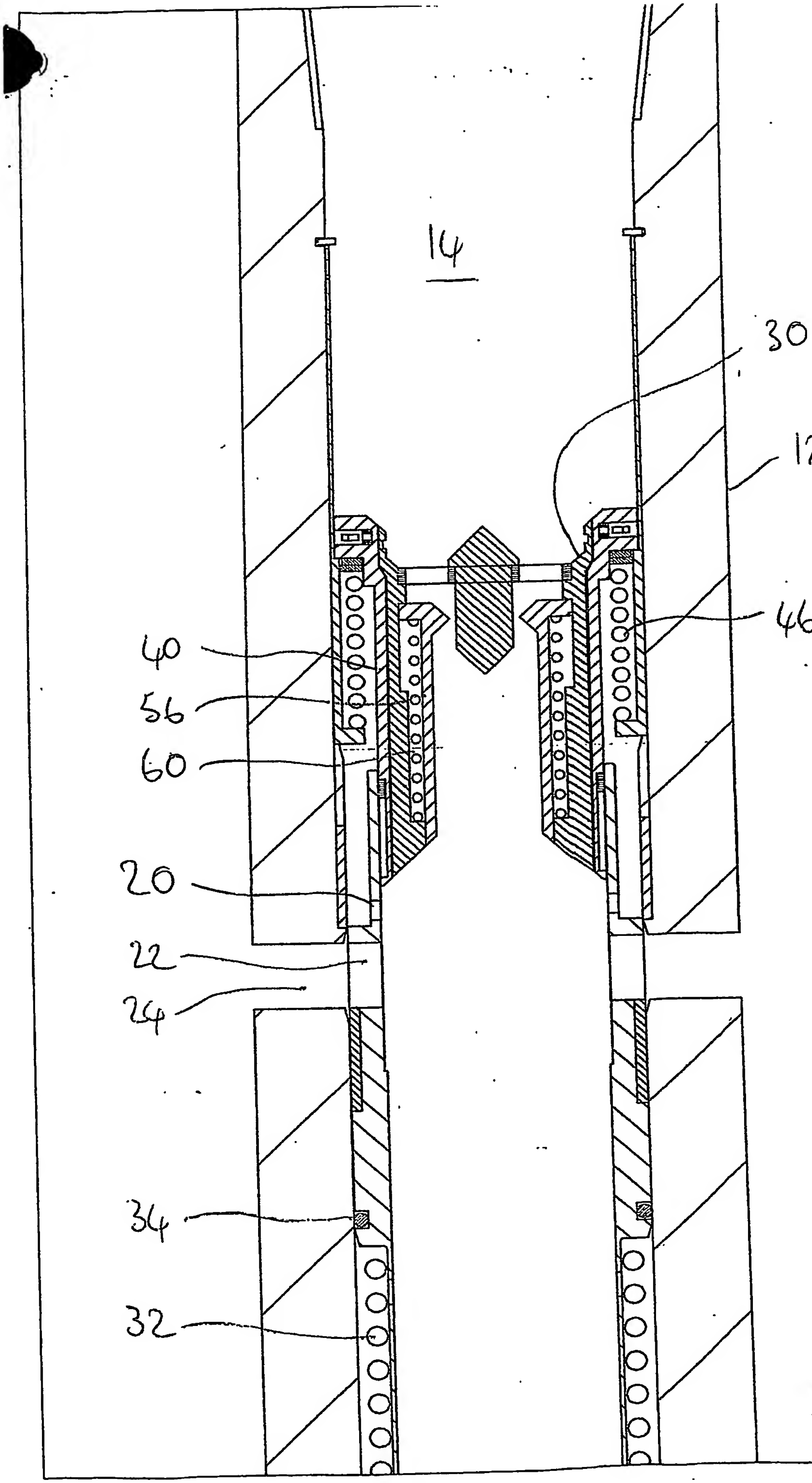


Figure 4L



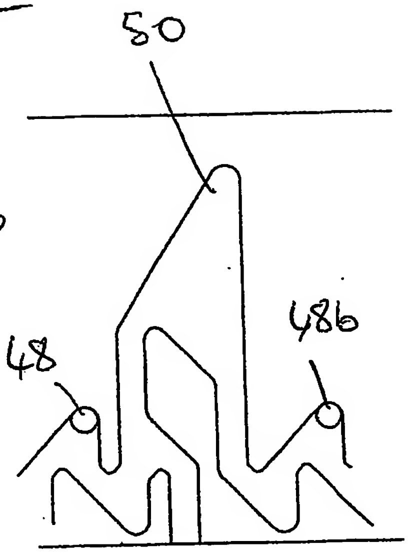


figure 5b

figure 5a

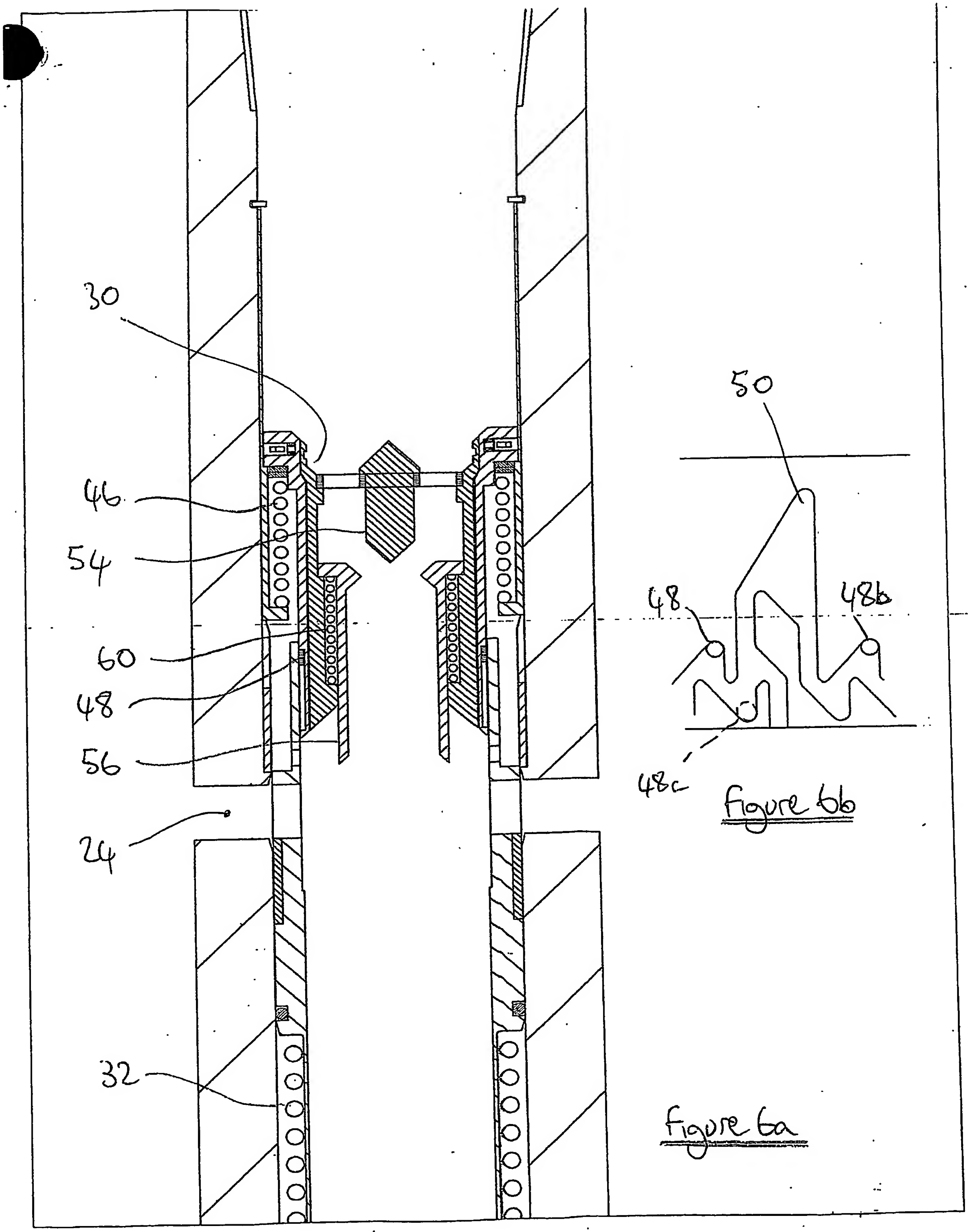
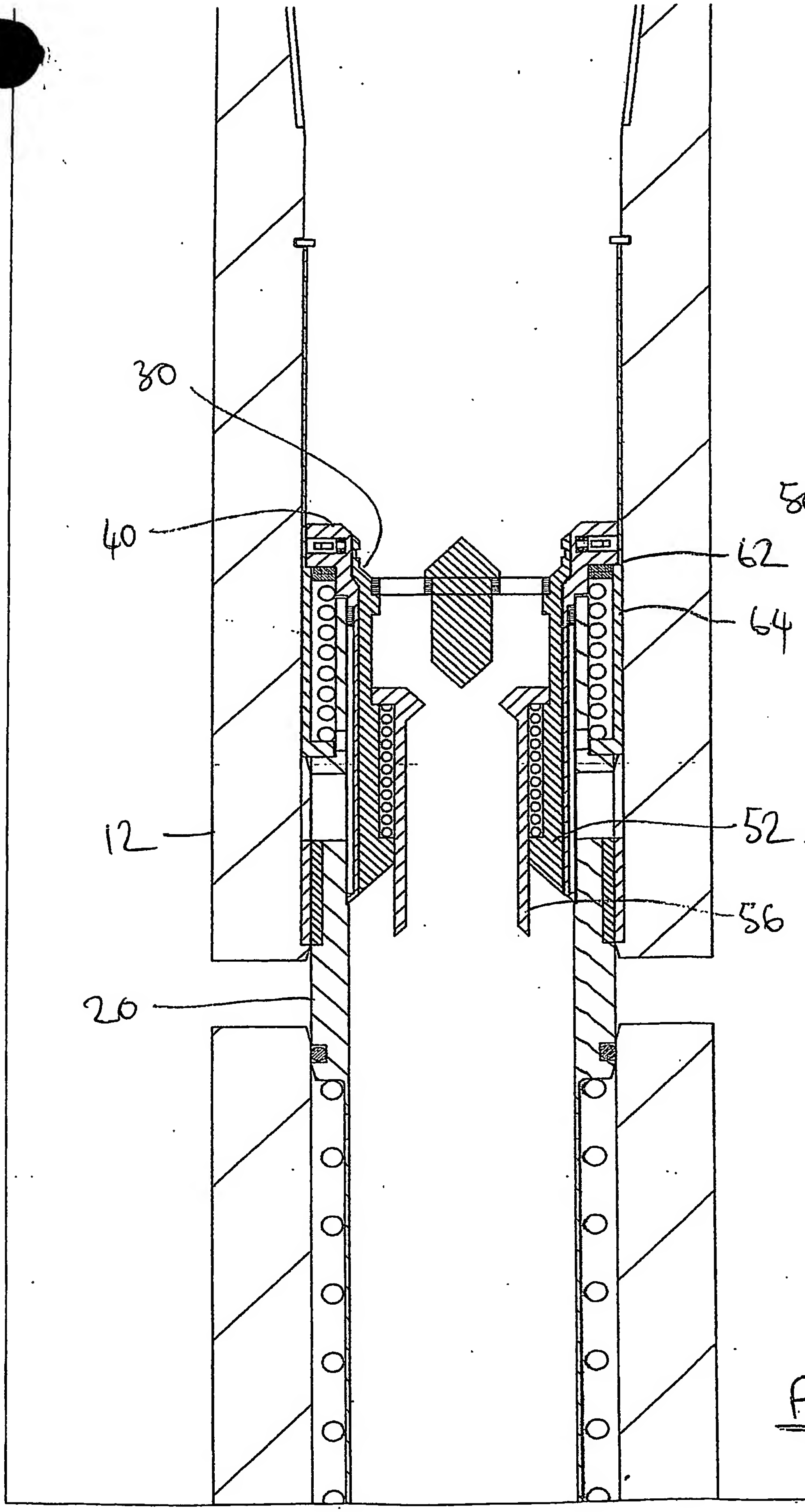


figure 6b

figure 6a



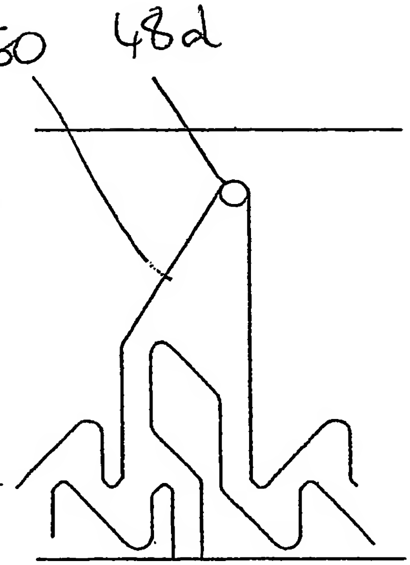


Figure 7b

Figure 7a

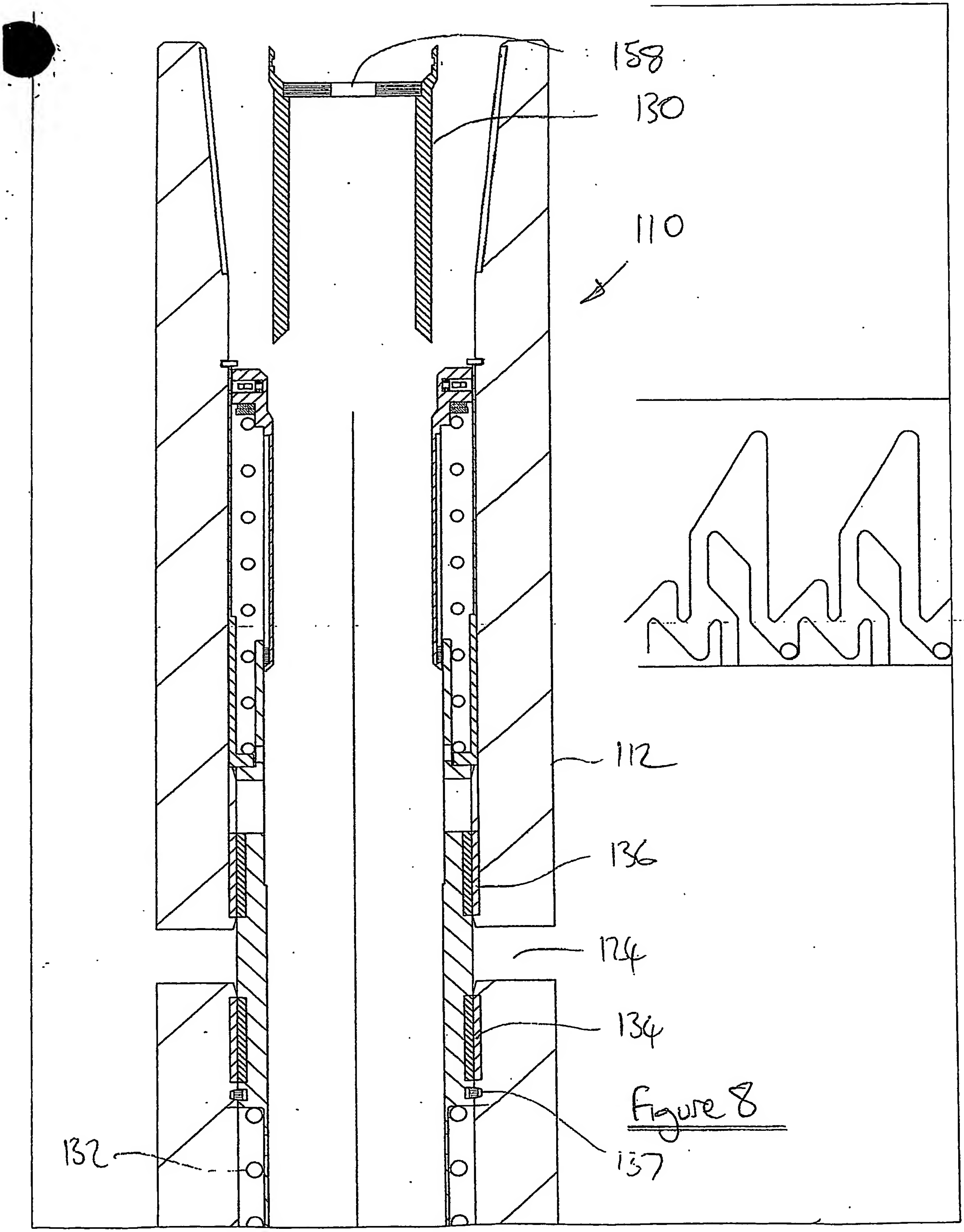


figure 8

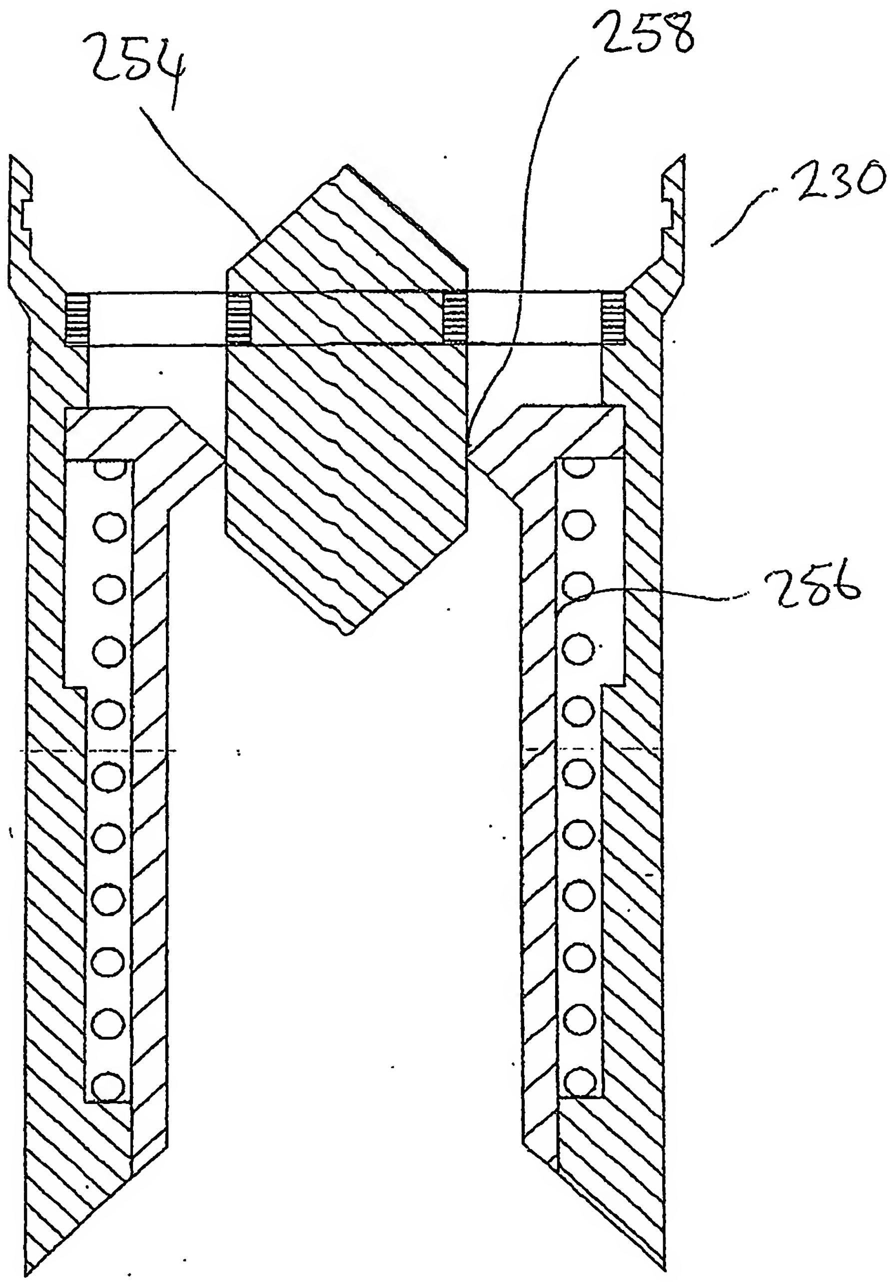


Figure 9

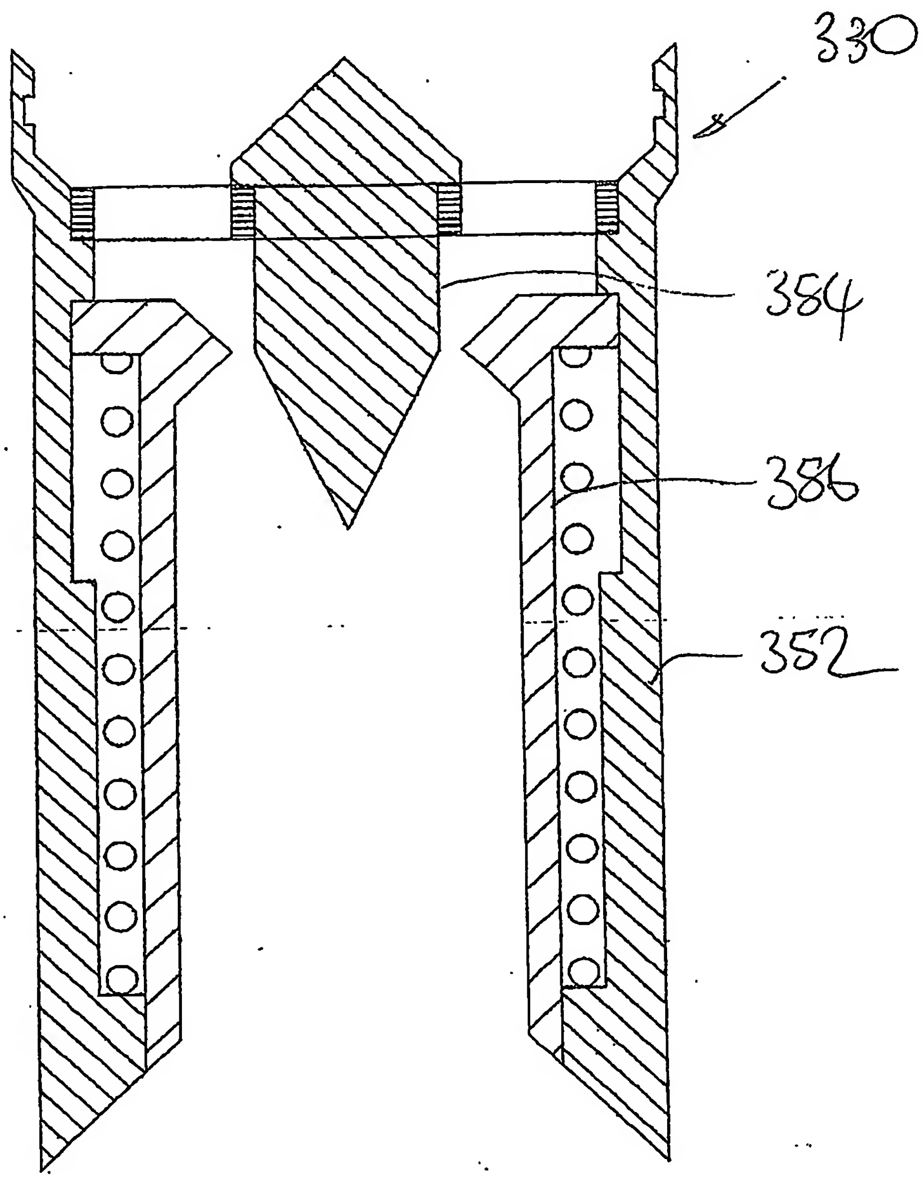


figure 10